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This report presents the results of Phase I of a three phase research program to develop a computerized economic analysis methodology appropriate for investment justification of robotics and flexible manufacturing systems (FMS) in aerospace manufacturing. Phase I surveyed methodologies for performing economic analyses of capital investments, and assessed their accuracy and supportability by Air Force contractors. The research concluded that the Tech Mod/IMIP computerized discounted cash flow model, recently promulgated by the Air Force, could be modified to perform economic analyses of specific robotics and FMS investment projects. This will require, in Phase II, adding the capability to the model to assess alternative robotics and FMS investment projects with different performance characteristics. A need was also identified for an investment analysis methodology with the capability to assess robotics/FMS projects based upon both economic and non-economic factors.

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FOREWORD

This document is the product of Phase I research for a three phase program entitled "Investment Justification of Robotic Technology in Aerospace Manufacturing," performed for the Air Force Business Research Management Center (AFBRMC/RDCB). In this program, Applied Concepts Corporation is developing a methodology for investment justification for robotic technologies in aerospace manufacturing applications. The criteria the methodology must meet are 1) it must be accurate, 2) it must meet the needs of Air Force organizations that make or fund investments in robotic technology, and 3) it must be implementable and supportable by Air Force contractors (manufacturers).

Phase I entailed: determining and evaluating existing economic analysis methodologies used by industry and the Air Force; identifying the most generally accepted methodology or methodologies; determining the feasibility of modifying an existing method to analyze the application of robotic technology; and making recommendations for Phase II. Phase II will be a development phase, where the selected methodology from Phase I will be modified, or a new methodology developed. The methodology will be in the form of microcomputer software. Phase III will be a validation phase, where the methodology developed in Phase II will be validated using data from an actual aerospace robotic application.

The project manager and principal author of this interim report was Mr. James A. Simpson. Mr. J. Scott Hauger and Mr. Robert L. Uphoff contributed to the technical work.

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INVESTMENT JUSTIFICATION OF ROBOTIC TECHNOLOGY IN AEROSPACE MANUFACTURING

Mr. Jim Simpson
Applied Concepts Corporation
109K North Main Street
Woodstock VA 22664

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I. METHODOLOGY AND INFORMATION SOURCES

1. Phase I was a survey and assessment of existing economic analysis methodologies to determine the feasibility of modifying them for analyzing potential applications of robotic technology in aerospace manufacturing. The survey encompassed three sources--the Air Force, selected aerospace contractors (manufacturers), and others such as academia, trade associations, professional journals, and published literature. The scope of the survey is summarized below.

2. Information Sources

a. <u>Air Force</u>

(1) The following Air Force organizations were surveyed, mostly through on-site personal interviews:

- ASD/YPM (F-16 Tech Mod Program Manager)
- ASD/PMD (Directorate of Manufacturing/Quality Assurance)
- ASD/PMD (PESO) (Product Engineering Service Office)
- ASD/PMDP (Manufacturing Management Division)
- ASD/PMF (Directorate of Pricing)
- ASD/PMFC (Analysis and Negotiations Division)
- ASD/ACC (Directorate of Cost Analysis)
- AFSC/PMI (Aerospace Industrial Modernization Office)
- AFWAL/MLTC (AFWAL's Robotics Group)
- AFWAL/MLTC (MANTECH's Tech Mod Group)
- HQ AFLC/MAXF (Equipment Group)
- HQ AFLC/MAXT (Facilities and Production Engineering)
- HQ AFLC/ACMCR (Management/Cost Analysis)
- HQ AFLC/PMMP (Contracts Management)
- HQ AFLC/XRPD (Plans and Programs Group)
- HQ AFLC/PMJ (Acquisition Concepts Office)

(2) Information was obtained from these organizations using the following questions:

(a) What is your role in robotics investment and robotics investment decision making?

(b) What methods do you use or require others to use for investment decision making; in particular, what special requirements or methodologies do you use for robotic technology or flexible automation?

(c) What is your assessment of the adequacy, accuracy, and supportability of existing investment justification methodologies?

(d) What are your preferences for how a robotics investment methodology would be structured, and your suggestions on how to design a methodology which would have high utility for the Air Force and industry?

(3) In addition to the information obtained from discussions with the above organizations, a large amount of documentary information was reviewed. This information was in the form of DoD, Air Force, AFSC, and AFLC regulations, instructions and directives on cost analysis, cost/benefit analysis, economic analysis, and technology modernization programs. Reports on relevant Air Force and DoD sponsored programs were also reviewed, such as the Robotics Application Guide, the Flexible Manufacturing Systems Handbook, and the IDEF factory analysis methodology.

b. Contractor Sources

(1) The following contractors were surveyed:

- General Electric Co., Aircraft Engine Business Group, Evendale, OH
- General Dynamics Corp., Ft. Worth Division, Ft. Worth, TX
- Northrop Corp., Aircraft Division, Hawthorne, CA
- Vought Corp., Dallas, TX
- Boeing Military Airplane Co., Wichita, KS
- AVCO, Aerostructures Division, Nashville, TN
- Cleveland Pneumatic Co., Cleveland, OH
- Honeywell Corp., Aerospace and Defense Division, Minneapolis, MN

(2) On-site discussions were held with each of the eight firms above. A number of secondary sources were reviewed which provided information on how other Air Force contractors perform economic analyses of advanced manufacturing technologies. These sources were primarily reports containing economic justification sections which had been submitted to the Air Force, and were available to the public. Many persons in the surveyed Air Force organizations were also knowledgeable of investment analysis methodologies used by contractors. Also, a number of personnel at on-site Air Force Plant Representative Office (AFPRO) and Defense Contract Audit Agency (DCAA) offices were interviewed. AFPRO and DCAA information sources were considered along with the contractors, because their perspectives strongly reflect the methodologies and circumstances at the particular contractor to which they are assigned. Finally, Applied Concepts Corporation's knowledge of investment justification methodologies obtained through past research programs was also exploited.

(3) The same four questions posed to the Air Force sources were posed to the contractors. Contractor discussions also addressed the ways in which inputs to investment analyses are generated, and how information for investment analyses is related to contracting and pricing activities. The discussions with the contractors encompassed the full range of the investment justification process. Because some of the issues which were

discussed involved proprietary matters, the linkage of findings to particular contractors was not undertaken. The findings and results focus upon general trends and patterns across all contractors.

c. Other Information Sources

(1) A library of more than 100 articles, books, reports, and other publications were obtained, providing information on existing practices in investment justification for robotic technology. A number of these, particularly from academic sources, provide recommended alternatives to existing approaches. The publications which were reviewed represented the following sources: trade associations, professional societies, federal laboratories, universities, equipment manufacturers, systems houses, foundations, and the trade press. Information obtained from these sources has been entered into a computerized data base. Discussions were held with a number of manufacturers, systems houses, academicians, and professional services firms that support the Air Force and its contractors in the Tech Mod program. A listing of these sources is provided below.

- Robotics Institute of America
- Society of Manufacturing Engineers
- American Management Association
- National Science Foundation
- Defense Technical Information Center
- Numberous USAF and DoD Cost Analysis and Economic Analysis Regulations
- Charles Stark Draper Labs
- Carnegie-Mellon Univ./Robotics Institute
- Virginia Polytechnic Institute
- U.S. Army Rock Island Arsenal (Robotics Program)
- U.S. Navy MANTECH and Tech Mod Programs
- Ford Robotics and Automation Applications Consulting Center
- Price Waterhouse
- Booz-Allen and Hamilton
- Robotics Applications, Inc.
- Cincinnati Milacron
- Robot Systems, Inc.
- Kaiser Engineers
- Stetler Assocs, Inc.
- Kearney and Trecker Corp.
- Over 80 articles, books, and papers

II. SURVEY FINDINGS

1. No unique methodologies were identified at the contractors that were specifically designed for robotics investment justification. Every contractor has its own internally required methodology and procedures which are followed to justify investment in any kind of new capital equipment. Formats typically involve a project description, a description of investment costs, a year-by-year analysis of the cash flows from the investment, and a computation of percentage return on investment (ROI) in discounted or inflation-adjusted terms.

Contractor methodologies are generally executed by filling out a series of required forms on which cost information is presented and manipulated. Generally, the greater the investment, the higher the management level which must authorize the expenditures. The corporate methodologies and requirements have evolved over time in response to corporate management's changing perceptions as to how best to assess alternative projects and optimally allocate capital investment resources. The sophistication of the methodologies and the analyses that are conducted with them vary greatly across companies, but no specially derived methods for assessing robotics applications are now in place, even among those firms heavily involved in robotics investment. No stochastic methodologies were found in current use for investment decision making.

2. Robotics and FMS investment decisions are rarely driven by economic factors, although economic analysis is used as one element of decision making. Economic analyses for equipment justification occur under three different stimuli with three different sets of associated criteria. These are:

a. Capacity Expansion. Opportunities for investment in new manufacturing technology are greatest at the initiation of a manufacturing program. Most investment in new plant and equipment in the defense aerospace sector takes place at program initiation and is justified largely by a capacity requirement. In these cases technical and operational considerations usually drive the decision-making process. Economic analyses may be performed to ensure compliance with company justification requirements, but the analyses are often very cursory or even perfunctory. Some companies do not require a detailed economic analysis when a capacity requirement or other non-economic factor (product quality, health and safety, delivery schedule) is the driver for the capital investment.

b. Replacement. In the defense aerospace sector the number of opportunities for introducing new manufacturing technologies for replacement of existing processes is limited. Replacement opportunities arise when current equipment nears the end of its economic service life. New technology equipment can then replace the older, less efficient equipment.

The compression of product life cycles that has occurred in the last two decades has meant that there is little time for equipment to wear out. Perhaps more importantly, the inherent uncertainties regarding future contracts and production volumes produce a tendency to "make do" with current equipment until the next program comes along.

Another factor discriminates against replacement expenditures. This is the fact that the high operating, maintenance, and repair costs of aging or obsolescent equipment can be passed on to the government immediately, and therefore most assuredly will be recouped. On the other hand, the purchase of new capital equipment imposes a future liability upon the company with no assurance that the necessary savings will be realized to recoup the investment.

c. Displacement. The situation with the least potential for new equipment investment is displacement of current equipment or processes. Manufacturing cost savings over time must be very large to offset both the purchase of the equipment and the risk of a lower than anticipated production requirement. Opportunities for this kind of implementation typically involve displacement of highly labor intensive processes with more automated ones. Health and safety concerns are sometimes a reason for displacement. However, the most common drivers for displacement are probably product quality assurance or other technical requirements.

In summary, the introduction of new manufacturing technology, including robotics and flexible manufacturing systems, is not usually driven by the economics of the particular application, but by broader program, contractual, and competitive factors. It is only in those potential implementations driven by economic factors that we find the effort required actually being expended to perform thorough economic analyses. Capacity driven investments are the easiest to get approved.

3. A robotics investment decision methodology should be compatible with Air Force approved investment analyses. There is great interest among contractors in the methodology the Air Force will use for investment analysis of proposed Technology Modernization (Tech Mod) Program projects. The key objective of contractors is to obtain a sufficient amount of the savings to meet corporate ROI hurdle rates. There is a great deal of uncertainty among contractors regarding the details of how to execute an economic analysis for Tech Mod, how to generate the required input information (particularly indirect costs), and how to integrate economic analysis information into pricing, rate setting, and contracting activities.

4. A new methodology for assessing Tech Mod investments will soon become available. The model is called the IMIP/Tech Mod model. It is a computerized spreadsheet model, which performs a discounted cash flow to compute a discounted ROI. It was designed to be flexible and user friendly, and to have the capability to address the full range of issues in traditional investment analysis of new equipment in defense aerospace manufacturing. The model is capable of handling the following kinds of

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Return on Investment (ROI)

factors:

- equipment acquisition cost
- equipment installation cost
- material acquisition cost
- engineering labor
- engineering overhead
- manufacturing labor cost
- manufacturing overhead
- CAS 409 depreciation
- Property taxes
- Insurance
- Maintenance costs
- CAS 414 and CAS 417 facilities capital cost of money
- Lost profit from savings
- Salvage value of equipment at end of analysis period
- ACRS depreciation
- Investment tax credits
- Retained productivity savings (RPS)
- Other direct costs
- Other indirect costs

The model outputs can be:

- DoD net program benefit without retained productivity savings (RPS)
- DoD net program benefit with RPS
- DoD payback period
- Total government benefit
- Contractor rate of return, without RPS
- Contractor rate of return, with RPS
- Contractor payback period

The model is attractive because it enables the user to perform analyses under a variety of assumptions and approaches. It is also attractive because it simulates quite well the cash flows that occur, particularly those due to CAS 409, 414, and 417, while enabling an after-tax analysis (ACRS, investment tax credits, etc.) to be taken. The projection of cash flows based upon CAS, coupled with an after-tax analysis (using ACRS, investment tax credits, etc.), means that this model can accurately predict the financial implications of new capital investment under typical USAF contracting methods. Versions will be available for the IBM PC and the Air Force COPPER IMPACT timesharing system.

5. The timeframe for investment analysis must be reconsidered if FMS is to be adequately considered. Investments for military programs with payback periods of more than two or three years now have little chance of obtaining management approval, if cost savings are the sole justification for implementation. A three or five year analysis period is common. Some firms use a 10 or 15 year analysis period even though a two or three year payback may be required. Some firms let the expected production base determine the length of the analysis period. In these cases the analysis

period rarely extends beyond five years. A fully adequate methodology would allow the user to specify the length of the analysis period.

6. Pricing and contracting arrangements have a major impact on a company's perspective of the economic attractiveness of a project. For example, if items are sold through firm fixed price contracts, the company normally receives all of the savings from manufacturing cost reductions, at least for awhile. However under cost-plus fee contracts, the government recoups all the cost savings. Furthermore, since profits are generally a percentage of costs, the absolute amount of the company's profits will be less if costs are reduced.

Fixed price contracts negotiated through forward pricing agreements may have less obvious but even more profound implications. Investment in the project under assessment already may have been included in the direct and indirect cost estimates submitted for the forward pricing agreement and the estimated resulting savings assumed. If this is the case, not making the investment would increase costs which could not be recouped by the company.

Economic analyses of Tech Mod projects may need to be adjusted to reflect forward pricing information. If the Tech Mod project is included in the estimated future cost projections upon which prices had been negotiated, subsequent Air Force funding support would be duplicative. The corollary to this is that DCAA may dispute a contractor's forward pricing cost estimates, which typically are based on historical trend analysis, that are out of line with DCAA projections. Robotics and FMS programs with large indirect costs may greatly complicate price negotiations and may require other programs or costs to be sacrificed. Progress payments must also be considered in the economic analysis. Thus, an economic analysis divorced from contracting and pricing considerations will usually not reflect the true economic impact on the company.

7. Product mix and company cost accounting procedures have major implications for the financial attractiveness of robotics and FMS projects. The main problem is the inability to allocate indirect costs of the robot or FMS to the specific parts produced or impacted by them.

Consider the example of a plant with a single manufacturing overhead rate producing a variety of parts for a variety of end items, under firm fixed price contracts. The introduction of robotics and FMS generally involves lower direct costs, and higher indirect costs than traditional equipment and processes already in place throughout the rest of the factory. Since indirect costs are allocated as a percentage of direct costs, the introduction of robotics or FMS in such a situation would result in other parts "subsidizing" the production of the parts produced with the robot or FMS.

A traditional economic analysis could show the robot or FMS application as very attractive, because a large portion of its indirect costs are borne by other charge centers. Even if a detailed analysis of direct and indirect costs indicated the application had a substantial net economic benefit (that is, if the direct cost savings significantly offset the increased indirect costs), it still would be very difficult to sell this program inside the company, due to the impacts upon the other programs and the implications for competitiveness on certain jobs. One solution for this problem is to set up a different, separate indirect cost accounting system for the robotic or FMS application. Another is to totally reconsider the meaning of "direct" and "indirect" costs. These are complex, expensive undertakings, and there are many administrative barriers to these approaches.

8. Many of the robots that have been procured to date by aerospace companies have been justified not as the result of assessment, but to enable assessment. The prime reason for many robot purchases is to determine the technical and economic feasibility of this technology. Many companies believe that robots may offer major opportunities for cost reduction in the coming years and want to familiarize their staff with this technology and with the problems of applying it in their particular production applications. The track records of these robot applications, not unexpectedly, show many disappointments. These findings are not as applicable to FMS. The FMS experience base is much more limited. Economic considerations appear to be more important for FMS implementation because of their very high procurement and installation costs.

9. Although direct and indirect manufacturing costs are often tracked extensively, they generally are not tracked functionally. Indirect costs in particular are rarely tracked to an individual piece of equipment or particular work station. They sometimes are not even tracked to the shop level. Cost tracking and accounting systems have been designed to meet the requirements of DCAA and IRS, but not of operations. Therefore there is a very limited capability to perform accurate, detailed assessments of the costs, particularly the indirect costs, of implementing robotic and FMS technology. The accuracy and validity of the economic assessments depend upon a very imprecise process of allocation. This holds true for both "As-Is" and "To-Be" economic assessments.

10. The long-term benefits of the flexibility of robots and FMS are not usually considered in the economic analyses performed by contractors. The known (no risk) or projected (low risk) business base is almost always used to determine equipment utilization. The main reason for this is procurement uncertainty. The result is that technology options which do not pay for themselves over a very short period of time are systematically or arbitrarily eliminated.

11. The commonly used analysis formats strongly reflect traditional cost accounting practices and data availability. They do not necessarily address the individual items that need to be evaluated for an accurate analysis and good decision making. Cost element breakdowns tend to reflect cost <u>accounts</u>, and not cost <u>factors</u>. The omission of cost factors is detrimental to a good economic analysis for technologies such as robotics and FMS, in which the indirect cost structure is substantially different

from other equipment and processes in the plant.

When indirect costs are allocated using the same assumptions and procedures as for less automated technologies, a very inaccurate picture of the true economic attractiveness of a proposed robotics or FMS project may result. Contractors' awareness of the weakness of this approach appears to be growing, and some contractors appear to be expending more effort to identify and assess at least the more important indirect costs. Given the usual lack of readily available information on indirect costs from the cost accounting system, identifying the full range of direct and indirect cost impacts of robotics/FMS implementation requires special detailed (and expensive) studies across departments.

12. The analysis methodologies that are now used have a limited capability to address operational dissimilarities among the alternatives analyzed. Such differences between alternatives could be production volume over time, product quality, value added, etc. For example, a robotic substitute for a manual drilling operation may be able to drill more holes over time than a manual process, and therefore might be more valuable even at a higher cost. Conversely, in some applications the robotic equipment may require substantial downtime for reprogramming, resulting in less work being done over time than with the manual equipment. Very seldom does one find that robotics or FMS can be introduced as a direct replacement for a manual operation, with no impact on outputs. Yet, current first order analysis methodologies almost always presume a like-for-like substitute in this regard.

13. Current analysis methodologies have a limited capability to address externalities of an implementation. For example, a robotic material handling system may put items to be processed in a better position than the manual approach, enabling more work to be performed at subsequent work stations. A reduction in work-in-progress and inventory may result. These incremental, yet very important externalities are rarely considered in a first order economic analysis.

14. Current methodologies have a very limited capability to address changes in the business base which may result from the implementation. The enhanced production capability from a robotic or FMS application may enable the company to bring in-house formerly contracted out work, or to bid on the production of additional parts or components. Again, a like-for-like substitution is assumed.

A related problem is that current methodologies cannot readily assess the economic impacts of alternative project scheduling. This is particularly important when one considers that an implementation may have to pay for itself over a short production schedule. It may be very important for an implementation to be phased in at the proper time, which would usually be at the initiation of a production program. If the robot or FMS misses the "window of opportunity" (that is, the introduction of the manufacturing program), its economic attractiveness will be reduced, due to reduced utilization and probably a reduced amount of avoided costs.

15. For contractor investments, verification or validation of projected economic impacts is not widely practiced. The general perception is that once the investment is made, it becomes a sunk cost and there is little to be gained from a post-implementation validation. After the implementation decision has been made, resources are focused on getting the technology implemented and making it work. Post hoc project performance assessments are not uncommon, however. By regulation, Tech Mod investments are subject to a validation requirement. However, this has proven to be extremely problematic, and has not been accomplished to date. The cost of tracking economic benefits over time is very high. Even a one-time, "snapshot" validation is very expensive.

16. It is a common perception among Air Force personnel involved in the Tech Mod program that contractors perform an inadequate estimation of the costs and impacts of introducing new robotic equipment and FMS. The track record is particularly bad in estimating the indirect costs of the installation and operation of these technologies. There is a strong perception that contractors are not adequately addressing group technology in their consideration of these technologies.

A number of Air Force personnel involved in the Tech Mod program stated that the major need was guidance on how to derive the data on the individual data elements, which become the inputs for an economic analysis. A decision tree, "cookbook", or "checklist" approach was suggested, which would guide the analyst step by step through the process of identifying the relevant cost factors and identifying their impacts and magnitudes. Most Air Force personnel believed that such a methodology in hard copy would be as effective as a computerized version. Another important benefit of addressing inputs, in addition to yielding a more accurate analysis, would be the standardization of the inputs going into the Tech Mod economic analysis model.

17. Air Force Logistics Command (AFLC) usually performs economic analyses for proposed equipment projects at the Air Logistics Centers (ALCs), unless funding is to come from one of several special programs. If system investment cost is between $10,000 and $100,000 (this is a common range for robotics projects), a computerized analysis through AFLC's GO-17 system is required. A cash flow procedure is used. To be approved, the project must show a payback of less than 10 years and a savings-to-investment ratio of greater than one. All equipment is assumed to have a ten year service life, and a 10% discount factor is used. Projects with costs above $100,000 require a manual economic analysis containing a more detailed written description of costs and anticipated payoffs. These are reviewed by the ALC controller, and then forwarded to AFLC for review and approval. Investments of less than $10,000 can be approved at the ALC. Many investments are justified on non-economic grounds, particularly health and safety, and through what is termed a "vital mission request". Even these are subjected to an economic analysis, however, for information purposes.

Non-economic factors probably justify the majority of new equipment purchases. The ALCs have an essential mission role, and a great deal of equipment is purchased to maintain required surge capacity. Worker health and safety is also an important reason for procuring equipment. Like the contractors, the ALCs also justify equipment purchases based on a capacity or capability requirement. When a new weapon system enters the inventory, the ALCs must prepare to maintain and repair it. Like the contractors, the initiation of a new program is commonly a time of major equipment procurement.

The format and content of AFLC economic analyses are mandated by regulation, and its existing models and procedures reflect those regulations. While the development of a robotics/FMS economic justification methodology for AFLC and the ALCs may be a desireable objective, it was found to be beyond the resources of this program. No readily modifiable methodology was identified which could provide a focus for development. The development of the methodology must be driven by the special requirements and capabilities of AFLC and the ALCs. Such a development effort would require a level of effort equal to or greater than that available for this entire program. For these reasons, it was decided to concentrate research efforts on the development of a methodology for Air Force contractors (manufacturers).

III. CONCLUSIONS AND RECOMMENDATIONS

1. There exists within the aerospace industry, no commonly used robotics and FMS investment decision methodology which adequately compares and assesses the costs and benefits of technologies' applications. The problem of identifying an adequate methodology is more complex than originally conceived. The crux of the matter is that AFBRMC and Applied Concepts understood the problem to be one of investment decision making based on the comparative cost effectiveness of robotics and FMS, versus traditional technologies. The basic problem was to determine how the special economic impacts of robotics and FMS should be accounted for in investment decision making. The elements of this problem were understood to include the need to account for the indirect cost implications of robotics and FMS in an appropriate manner, and the need to develop a method, probably stochastic, to account for the added value of robotic and FMS flexibility.

All of these problems remain. In the course of Phase I research, however, the research team has come to understand that other considerations typically outweigh, in investment decision making, the economic issues which this project was designed to address. Our concern is that the development of a methodology, however excellent, which centers on economic issues alone, will be peripheral to real-world decision making. This is not to say that an economic investment decision model is valueless. It is to say that an economic decision methodology should be conceived as one element of a broader approach.

2. What is required is a methodology which will allow a decision maker to establish evaluation criteria, prioritize them in some way, and score each alternative according to how well it satisfies the evaluation criteria. Some of those criteria will be economic. Economic criteria will have a certain relationship (different relationships for different decisions), with operational effectiveness and supportability criteria.

The methodology should have a capability to consider financial impacts together with non-financial impacts within an overall evaluation context. It should also have the capability to assess them separately, and then to compare economic and non-economic assessment results in terms of the value of the new technology in use and the cost of the new technology in use.

Applied Concepts is familiar with a model which can be modified to perform this function. This is the Multiple Criteria Decision Model (MCDM), which was developed by USAF's Aeropropulsion Laboratory for Air Force-wide use as a generic model for performing comparative, multivariate assessments of how well alternative advanced technologies meet various mission requirements. It was developed by AFWAL/POOC to run on an ASD mainframe computer (Control Data Cyber 176). Applied Concepts has used this model previously under Air Force contract. Last year, Applied Concepts modified the model to correct several faulty algorithms, and then converted it to run on an Apple II microcomputer with 64K RAM. The microcomputer version, which we call the Multiple Attribute Decision Model (MADM), suffers no decrease in technical capability from the mainframe version, and is superior in terms of user friendliness. It is now totally menu driven and requires absolutely no programming knowledge on the part of the analyst who uses it.

3. MADM can incorporate dissimilar attributes, allow user specification of the relative importance of the evaluation factors, output non-economic results in terms of utility values, and allow a quantitative expression of professional judgement. Our research has found this to be an excellent model with the potential for meeting the requirements of a comprehensive investment justification methodology for robotics and FMS. The main modifications to MADM that would be required to use it for this project are:

a. Changing terminology to reflect an investment project assessment instead of a technology assessment.

b. Modifying several utility programs.

c. Preparing a user's manual.

d. Developing a graphics output capability, to depict cost-effectiveness and other cost-payoff relationships.

LMI's model.

4. The IMIP/Tech Mod model mentioned in Section II will soon be the DoD standard for evaluating contractors' proposed Tech Mod programs, and for projecting the amount of savings available for sharing. It has many improvements over previous models, and quite nicely simulates actual cash flows that result from alternative investment programs. It was designed to be a rather high level model, where specific contractor investment projects would be aggregated and assessed as a whole program. It will provide a standardized methodology for assessing the economics of Tech Mod programs, and it will facilitate the establishment of business deals between contractors and the government. Since the financial incentives granted by the Tech Mod program, by regulation, may be based solely on dollar savings, non-economic factors purposefully were not incorporated into the IMIP/Tech Mod model.

5. The IMIP/Tech Mod model cannot be used directly as the economic portion of a robotics/FMS investment decision model, but it can be modified to provide a better methodology than any other which we have identified as being in general use or in development for general use.

6. The IMIP/Tech Mod Model can accurately assess only alternatives which are perfect like-for-like substitutes in terms of system performance and other outputs (e.g. production volume, value added, upstream or downstream economic benefits, etc.). Since it only considers the costs of alternatives, it cannot accurately assess alternatives which have different outputs. This is an important requirement for a robotics and FMS assessment methodology. These technologies typically have major

performance differences from the technologies they replace, and have other wide ranging impacts on the shop floor and on support and integration functions. What is required is to modify the IMIP/Tech Mod model to enable it to perform a normalized economic assessment which considers costs in relation to system performance and other outputs.

7. The research team takes note of the disincentives for robotics and FMS and new manufacturing technology in general which seem to be inherent to the traditional contracting methods of USAF, and traditional accounting methods as supervised by DCAA. This is partly a problem of institutional inertia, and is well beyond the scope of this study or its ability to influence change. Nonetheless, AFBRMC should be cognizant of this problem and should consider sponsoring future research to address this issue.

8. As a consequence of Phase I research, the research team recommends that the scope of the Phase II effort be expanded so that an investment decision model can be developed which can compare robotic and FMS technology applications with alternative technologies based upon a consideration of operational and supportability factors as well as economic variables.

9. Realizing that resources may not be available for an expanded model, the research team recommends that the best alternative consistent with existing resources is to develop a modified IMIP/Tech Mod model. The modifications should include a capability to make normalized comparisons which consider costs in comparison to system performance. They should consider, if possible, a stochastic approach to accounting for long term benefits of flexibility. This modified IMIP/Tech Mod model should be designed for future integration into an expanded, comprehensive investment decision model which incorporates non-economic factors.